Code

رابعة اتصالات

مقرر optics

part(9)

Sec (9)

In last section : $\boxed{I(z) = I_0 e^{\gamma z}}$

irradiance at z ; I_0 ← Input irradiance

Where :

$$\gamma = \frac{B\, \rho(\nu)\, h\nu}{v} (P_e - P_{abs}) \rightarrow ①$$

(ν ← freq.)

$$B = \frac{v^3}{8\pi h \, f^3}$$

(v ← velocity, f ← freq)

$$\rho(\nu) = \frac{(2m_r)^{3/2}}{\pi \hbar^2} (h\nu - E_g)^{\frac{1}{2}}$$

$I(z) > I_0 \rightarrow$ when $\gamma \rightarrow +ve \Rightarrow \gamma \rightarrow$ Gain / Amplificat.

$I(z) < I_0 \rightarrow$ when $\gamma \rightarrow -ve \Rightarrow \gamma \Rightarrow$ Attenuation / loss

↳ Condition of Amplification Gain :

$\gamma \rightarrow +ve$ (In eqn ①)

when ① $P_e > P_{abs}$

② $\rho(\nu) \rightarrow +ve$

when $\boxed{h\nu > E_g}$

↳ $P_e > P_{abs}$ In Quasiequlibrium :

$$P_e = f(E_2)\left[1 - f(E_1)\right] = \frac{1}{1+e^{(E_2-E_{fc})/KT}}\left[\frac{e^{(E_1-E_{fv})/KT}}{1+e^{(E_1-E_{fv})/KT}}\right]$$

$$P_{abs} = f(E_1)\left[1 - f(E_2)\right] = \frac{1}{1+e^{(E_1-E_{fv})/KT}}\left[\frac{e^{(E_2-E_{fc})/KT}}{1+e^{(E_2-E_{fc})/KT}}\right]$$

$\therefore P_e > P_{abs}$

When $e^{(E_1 - E_{fv})/KT} > e^{(E_2 - E_{fc})/KT}$

$$E_1 - E_{fv} > E_2 - E_{fc}$$

$$E_1 - E_2 > E_{fv} - E_{fc}$$

or

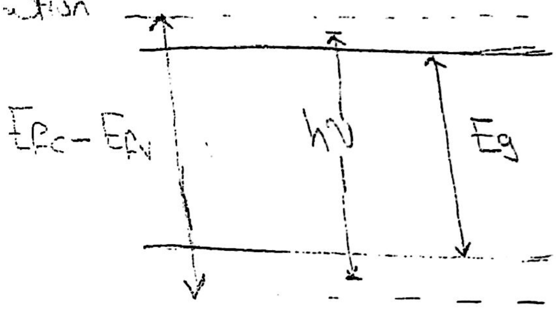
$$E_2 - E_1 < E_{fc} - E_{fv}$$

$$h\nu < E_{fc} - E_{fv}$$

$\hookrightarrow \gamma \to +ve$ when $\boxed{E_g < h\nu < E_{fc} - E_{fv}}$

Condition of Amplification

$$\underbrace{\frac{E_g}{h}}_{\nu_1} < \nu < \underbrace{\frac{E_{fc} - E_{fv}}{h}}_{\nu_2}$$



$$B.W = \nu_2 - \nu_1$$

In sheet ④ : Q(5) - ⑨ Estimate Conditions for Amp. (Stimulated emission)

← اجابته من الصفحتين (الاولى وهذه) .

ⓕ Amplification Gain in Stimulated emission

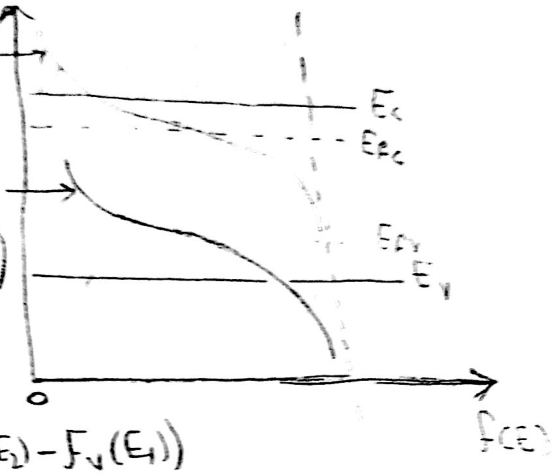
← اجابته كل الاثبات لحد الوصول لـ γ " من السكشن اللي فات "
+ ص٣ في هذا السكشن

$\hookrightarrow \therefore P_e - P_{abs} = f_c(E_2)[1-f_v(E_1)] - f_v(E_1)[1-f_c(E_2)]$

$= f_c(E_2) - \cancel{f_c(E_2) f_v(E_1)} - f_v(E_1) + \cancel{f_v(E_1) f_c(E_2)}$

$$\boxed{P_e - P_{abs} = f_c(E_2) - f_v(E_1)}$$

$$\gamma = \frac{\nu^3 \; \cancel{k\rho}}{8\pi h \cancel{\rho^3} \cdot \nu} \cdot \frac{(2m_r)^{3/2}}{\pi \hbar^2} (h\nu - E_g)^{1/2} (f_c(E_2) - f_v(E_1))$$



$$\therefore \gamma = \frac{\nu^2 (2m_r)^{3/2}}{8\pi^2 \tau_r \hbar^2 \nu^2} (h\nu - E_g)^{1/2} (f_c(E_2) - f_v(E_1))$$

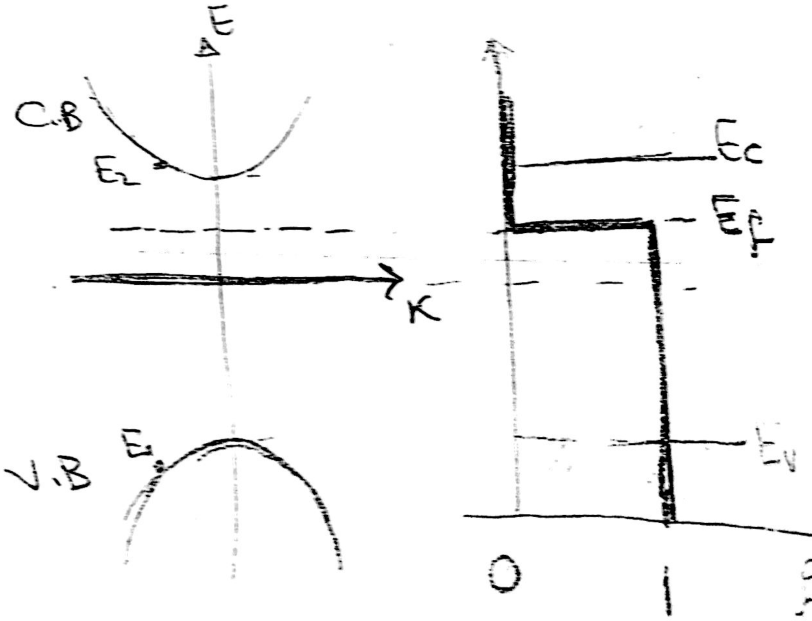
$$\gamma = \frac{(c/n)^2 \cdot (2m_r)^{3/2}}{2\tau_r (h\nu)^2} (h\nu - E_g)^{1/2} (f_c(E_2) - f_v(E_1))$$

$$\gamma = \underbrace{\frac{(c/n)^2 (2m_r)^{3/2}}{2\tau_r \hbar^2}}_{\text{Constant}} \cdot \frac{(h\nu - E_g)^{1/2}}{\nu^2} [f_c(E_2) - f_v(E_1)]$$

Case (1)

at Thermal equlibrium

$\boxed{T = 0K}$



$$f(E) = \frac{1}{1 + e^{(E-E_f)/KT}}$$

at $E_2 > E_f$ (C.B)

$f(E_2) = 0$

$E_1 < E_f$ (V.B)

$f(E_1) = 1$

$\therefore f(E_2) - f(E_1) = 0 - 1 = -1$

$\hookrightarrow \gamma \rightarrow -ve$

$$\gamma(\nu) = \text{Const.}\ \frac{(h\nu - E_g)^{1/2}}{\nu^2} \quad (-1)$$

$\hookrightarrow$ Draw $\gamma(\nu)$ vs. ν

في دالتين محتاجة ارسمهم ←

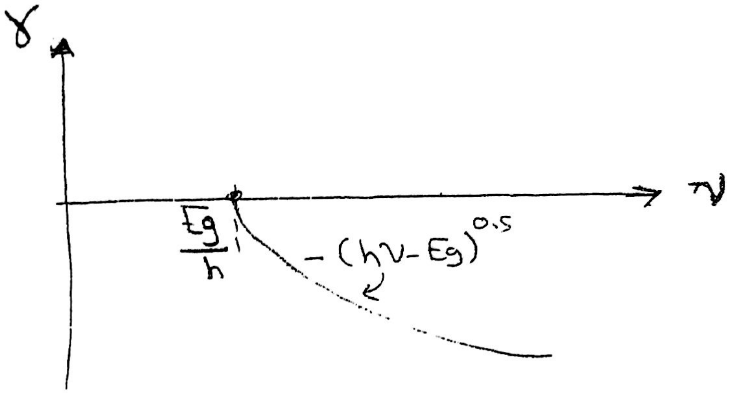
$-(h\nu - E_g)^{0.5}$

& $\frac{1}{\nu^2}$

$\hookrightarrow \Delta\nu = 10^{13}\ Hz$

$\nu = 10^{14}\ Hz$

$\hookrightarrow$ لذلك باعتبر المقام ثابت



Case (2) Quasi-equlibrium & T = 0K

$E_g < (E_{fc} - E_{fv}) < h\nu$

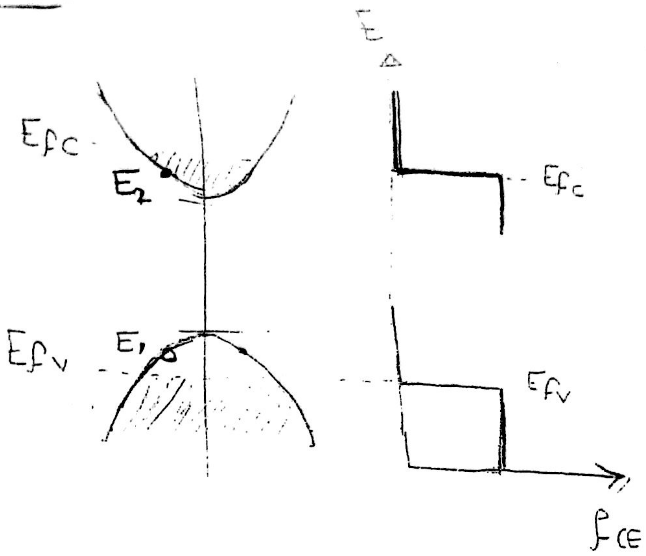
$f(E_2) = 1$

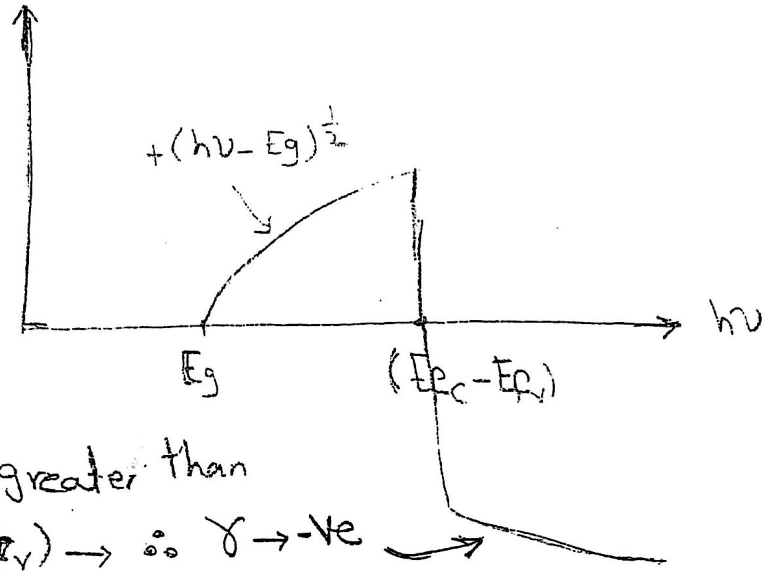
$f(E_1) = 0$

$f(E_2) - f(E_1) = +1$

$\gamma \rightarrow +ve$

Amplification Gain





When (hν) become greater than $(E_{fc} - E_{fv}) \rightarrow \therefore \gamma \rightarrow -ve$

↳ Quasi-equlibrium & T = 300K

at $h\nu < (E_{fc} - E_{fv})$

↳ $\gamma \rightarrow +ve$

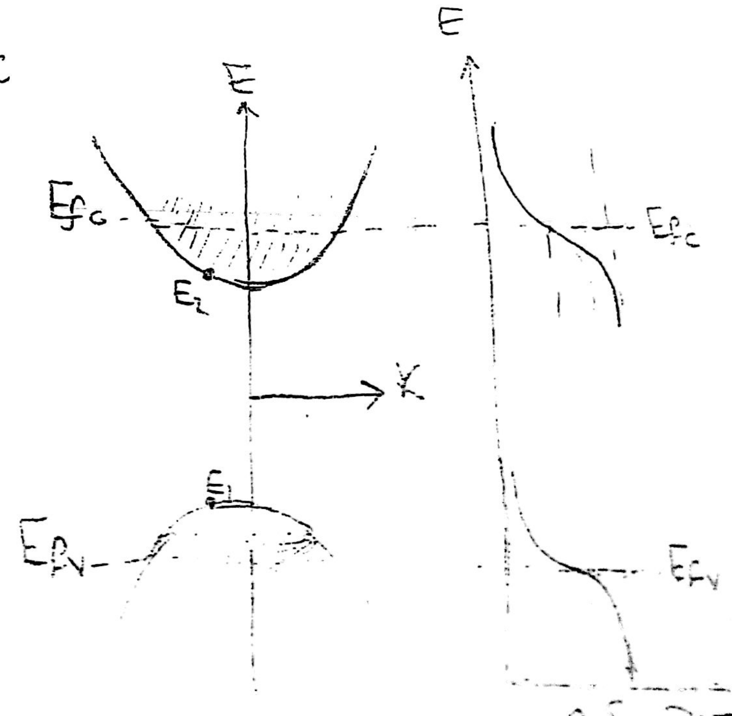
at $h\nu = (E_{fc} - E_{fv})$

$f(E_2) = 0.5$, $f(E_1) = 0.5$

$\gamma = 0$

at $h\nu > (E_{fc} - E_{fv})$

↳ $\gamma = -ve$



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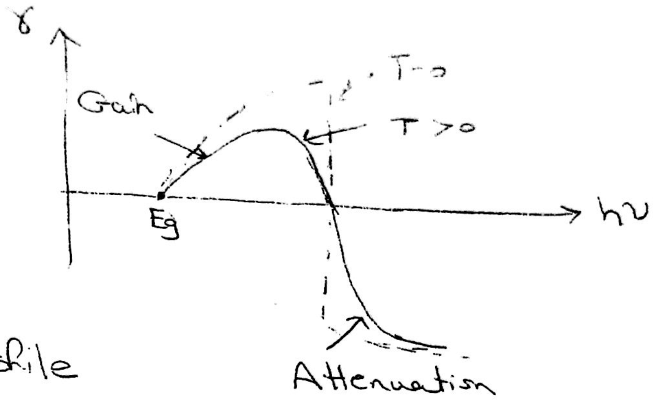
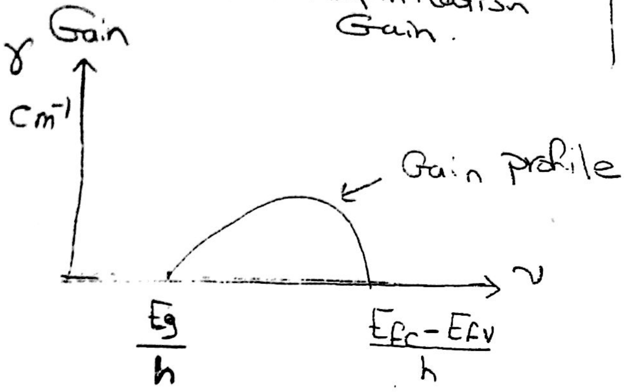
↳

↳ AT $\underline{T \geq 0K}$ ⇒ Amplification Gain.





$$\nu_{min} = \frac{E_g}{h}$$

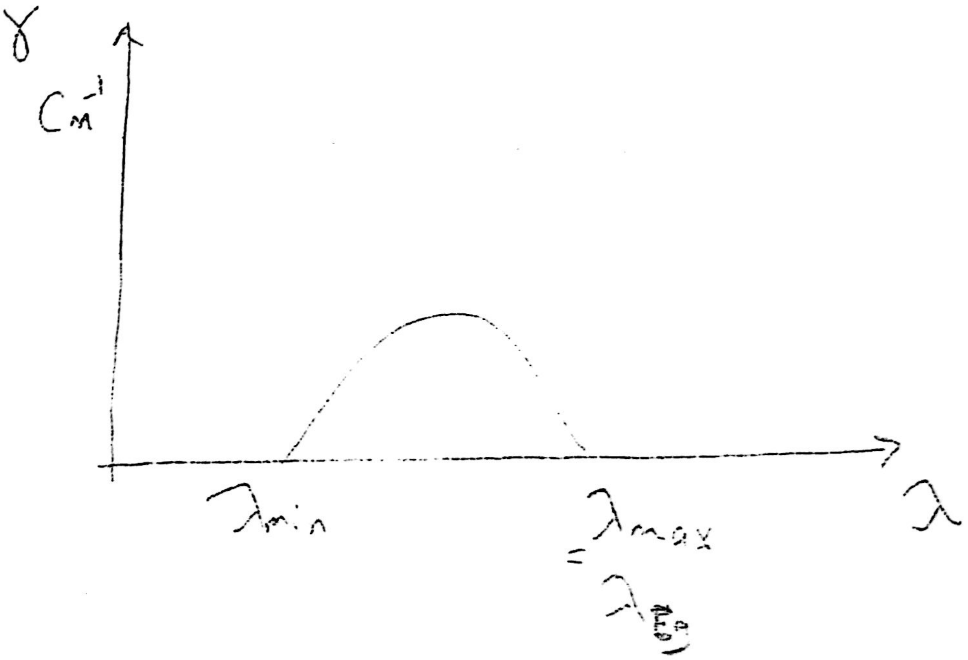
$$\frac{c}{\lambda_{max}} = \frac{E_g}{h} \Rightarrow \lambda_{max} = \frac{c \cdot h}{E_g}$$

$$\boxed{\lambda_{max} = \frac{1.24}{E_g}}$$

$$\boxed{\lambda_{max} = \lambda_{E_g}}$$

$$\nu_{max} = \frac{E_{fc} - E_{fv}}{h} \Rightarrow \frac{c}{\lambda_{min}} = \frac{E_{fc} - E_{fv}}{h}$$

$$\boxed{\lambda_{min} = \frac{c \cdot h}{E_{fc} - E_{fv}} = \frac{1.24}{(E_{fc} - E_{fv})}}$$



Q] Given Semi Conductor amplifier $In_{1-x} Ga_x As_{1-y} P_y$ with $E_g = 1.24$ ev, has a peak gain coeff. of $75 cm^{-1}$ and Amplification Bandwidth of 100 nm.

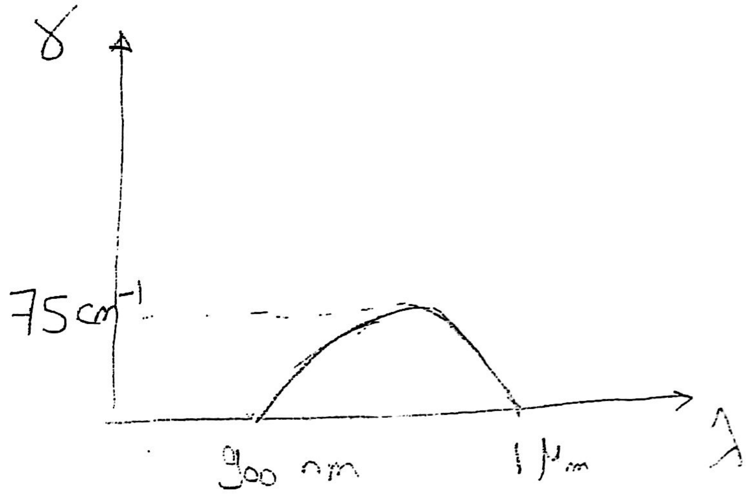
Draw qualitatively the variation of gain Coeff. with wavelength in the Amp. band.

~Sol~

$$\lambda_{max} (\text{Corresponding to } E_g) = \frac{1.24}{1.24} = 1 \mu m$$

$\because$ Amp. B.W = 100 nm $\Rightarrow$ $\Delta\lambda = 100 nm$

$\lambda_{min} = 1 \mu m - 100 nm = 1000 nm - 100 nm$
$= 900 nm$



sheet (4) Q(7) Given Semi Conductor Amp. $In_{1-x} Ga_x As_{1-y} P_y$ with $E_g = 1.12$ ev & peak gain Coeff. $= 60 cm^{-1}$ and B.W = 300 nm, draw the variation of Gain Coeff. ① with wavelength

② with freq.

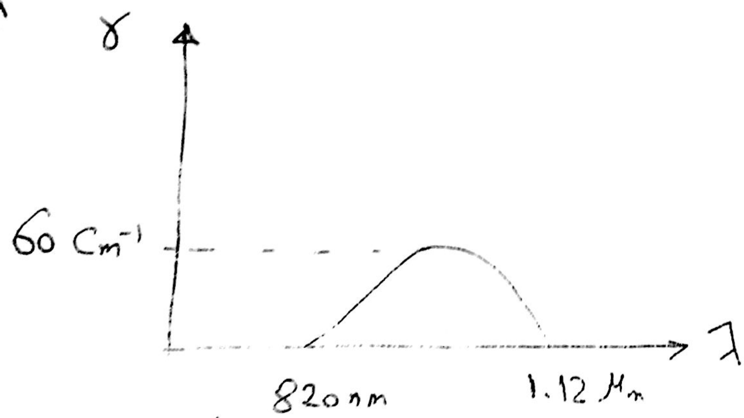
Sol

① $\lambda_{max} = \frac{1.24}{E_g} = \frac{1.24}{1.12} = 1.12\ \mu m$

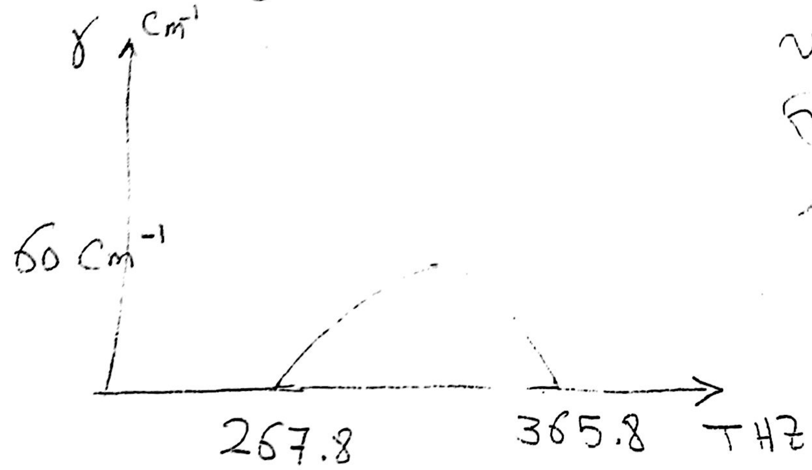
$B.W|_{\lambda} = 300\ nm$

$\lambda_{min} = (1.12 * 10^3)\ nm - 300 = 820\ nm$

γ Vs. λ



γ Vs. ν



$\nu_{max} = \frac{c}{\lambda_{min}}$

$\nu_{max} = 365.8\ THz$

$\nu_{min} = \frac{c}{\lambda_{max}}$

$\nu_{min} = 267.8\ THz$

$\Delta\nu = 98\ THz$

$(\sim\nu)$

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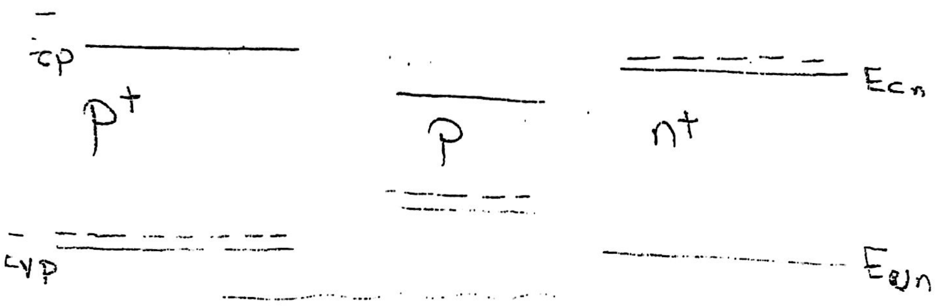
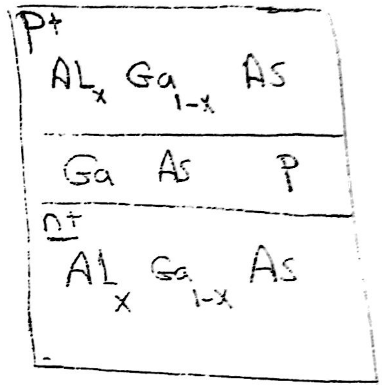
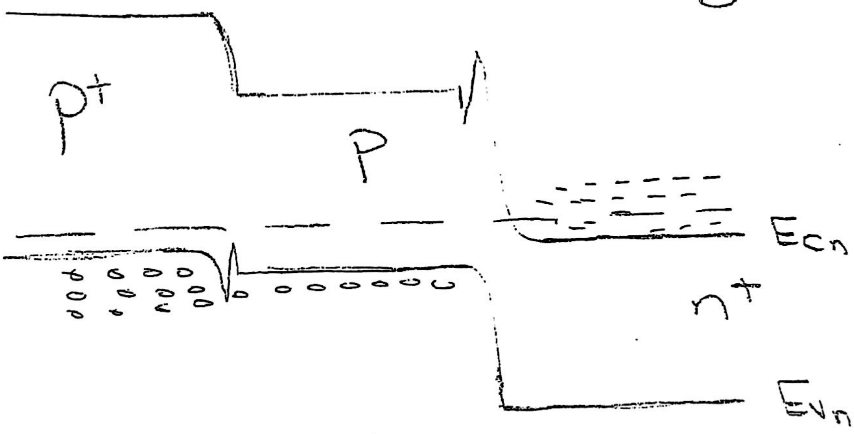
How to make $P_e > P_{abs}$? (or Why we use ~~Man~~ Man Double Hetero structure In Laser Amp ?)
or $(E_{fc} - E_{fv}) > E_g$

& Using Man structure Double Hetero structure
# it is ~~nessacary~~ nessacary to use Highly dopped matieral to design ~~soo~~ source act as amplifier.



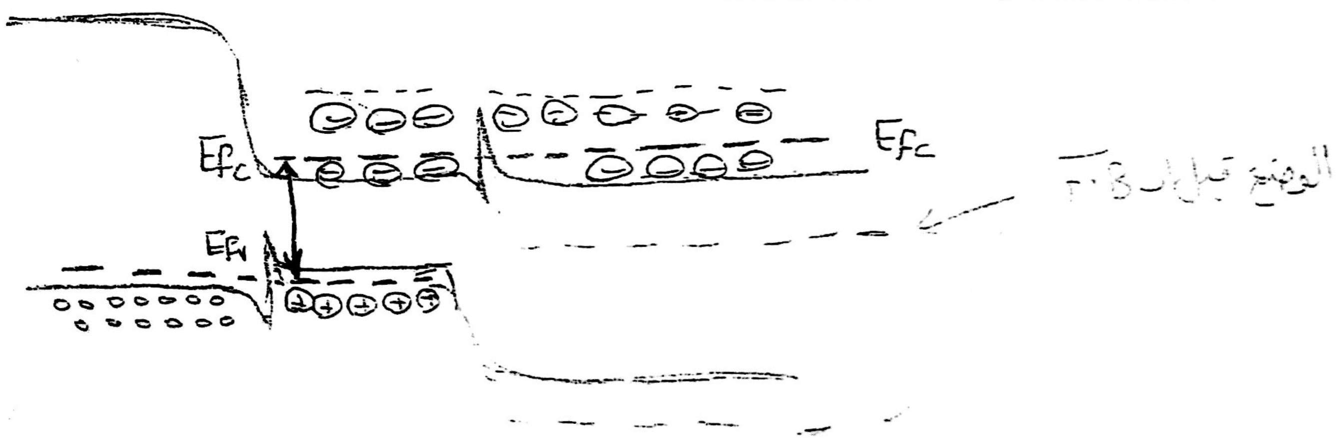


① Band Diagram without Biasing



② After F.B Biasing

$$\boxed{(E_{fc} - E_{fv}) > E_g}$$



Absorption spectrum of Semi Conductor

$$I_{in} \longrightarrow \boxed{S.C} \longrightarrow I^{out} = I_{in}\, e^{\gamma z}$$

semiconductor

$$\gamma = \frac{(c/n)^2\,(2m_r)^{3/2}}{2\,\tau_r\,\hbar^2} \cdot \frac{(h\nu - E_g)^{\frac{1}{2}}}{\nu^2}\,\big(f_c(E_2) - f_v(E_1)\big)$$

→ if $\underline{\gamma \rightarrow -ve}$ $\quad \underline{\gamma < 0}$ $\quad$ when $f_c(E_2) < f_v(E_1)$

Reverse Bias ← Pn-Junction يتحقق بتوصيل

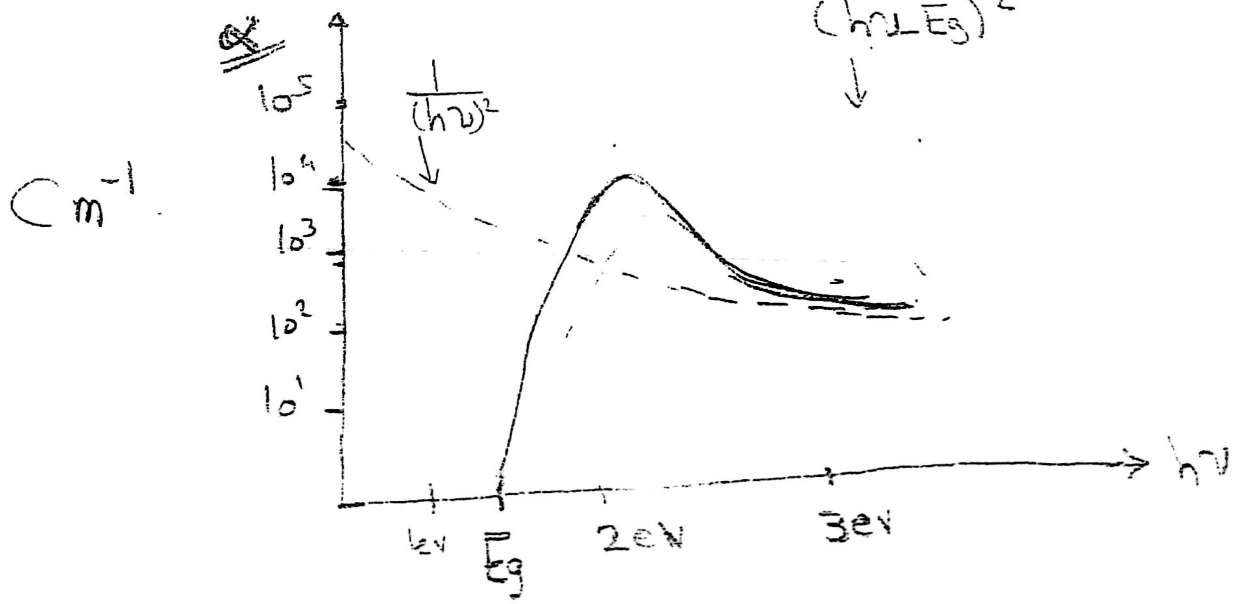
$$\gamma = -\frac{(c/n)^2\,(2m_r)^{3/2}}{2\,\tau_r\,\hbar^2} \cdot \frac{(h\nu - E_g)^{\frac{1}{2}}}{\nu^2}\,\big(\underbrace{f_v(E_1) - f_c(E_2)}_{+ve \text{ قيمة}}\big)$$

let $\gamma = -\alpha$

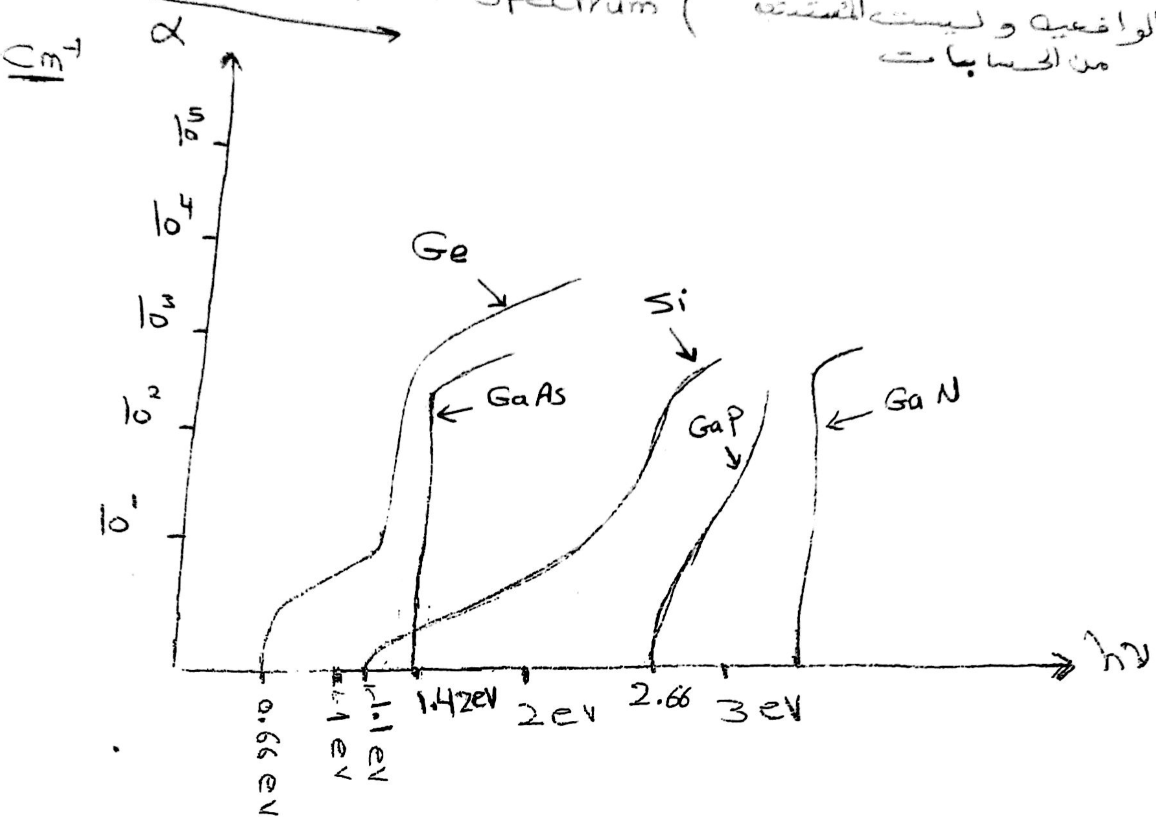
$$\alpha = \frac{(c/n)^2\,(2m_r)^{3/2}}{2\,\tau_r\,\hbar^2} \cdot \frac{(h\nu - E_g)^{\frac{1}{2}}}{\nu^2}\,\big(f_v(E_1) - f_c(E_2)\big)$$

Attenuation Coeff.

→ Draw Attenuation or (Absorption) Spectrum:



Typical Absorption spectrum (الواقعية وليست المستنتجة من الحسابات)



GaAs & GaN → Direct BandGap Materials

مجرد ما يكون الـ ($h\nu$) الساقط = Eg ⇐ هيحصل Absorption

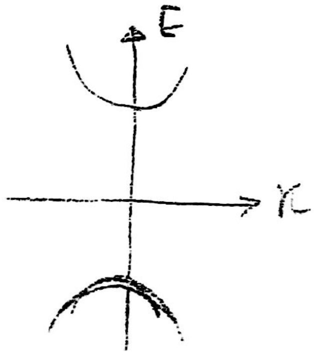
لذلك الخطوط vertical

Ge, Si, GaP → Indirect BandGap Materials

⇐ اي Material لها indirect Band لها direct اكبر منها

لذلك التغير في الاول بطيء لكن اول ما يوصل لقيمة معينة بيتغير سريع

⇐ لماذا يختلف الـ Attenuation Curve في حالة الـ typical عن الحالة الـ Theortical ؟

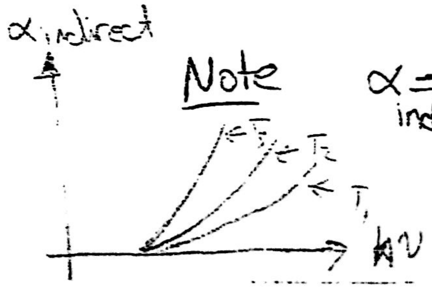


دة الغرض اللي بنيت عليه الحسابات

① ⇐ لأن في الـ Theortical ⇐ باستخدم الـ Parabolic Approximation

⇐ لكن اي Material بيكون فيها الـ Direct & indirect

Note $\alpha_{indirect} = (K_0 + K_1 T)(h\nu - E_g)^2$

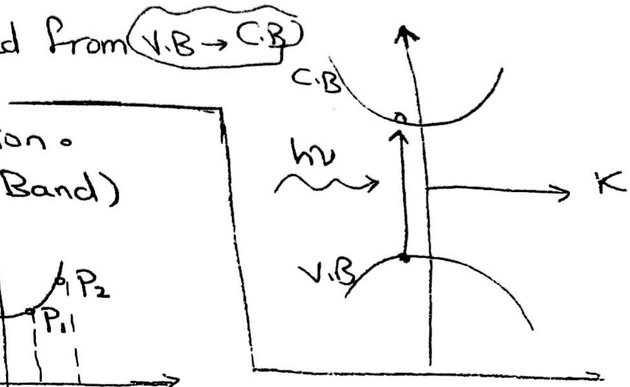


≠ α theortical

* Effects of Absorption

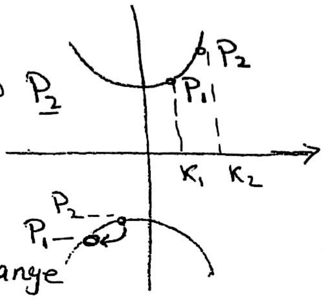
1. Inter band transition (Band-to-Band transition)

Electron excited from (V.B → C.B)



2. Interaband transition.
   (~~Ba~~ Within the Band)

Electron in position P_1 ~~to~~ make transition to P_2
(this will require phonon assistant because there is change in momentum)

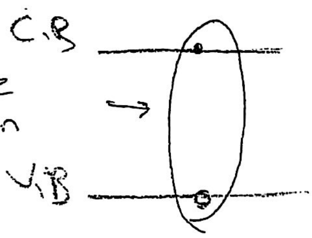


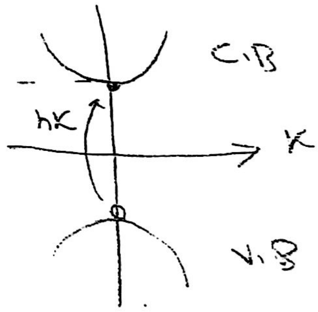
→ electron in P_2 → make transition to hole in P_1
[means hole moved up]

3. phonon transition (0.01 eV → 0.1 eV)

4. Excitonic transition: excited Electron hole pair

Behave as exciton →





if i excited Electron from V.B → C.B

+ve charge will be in edge of V.B

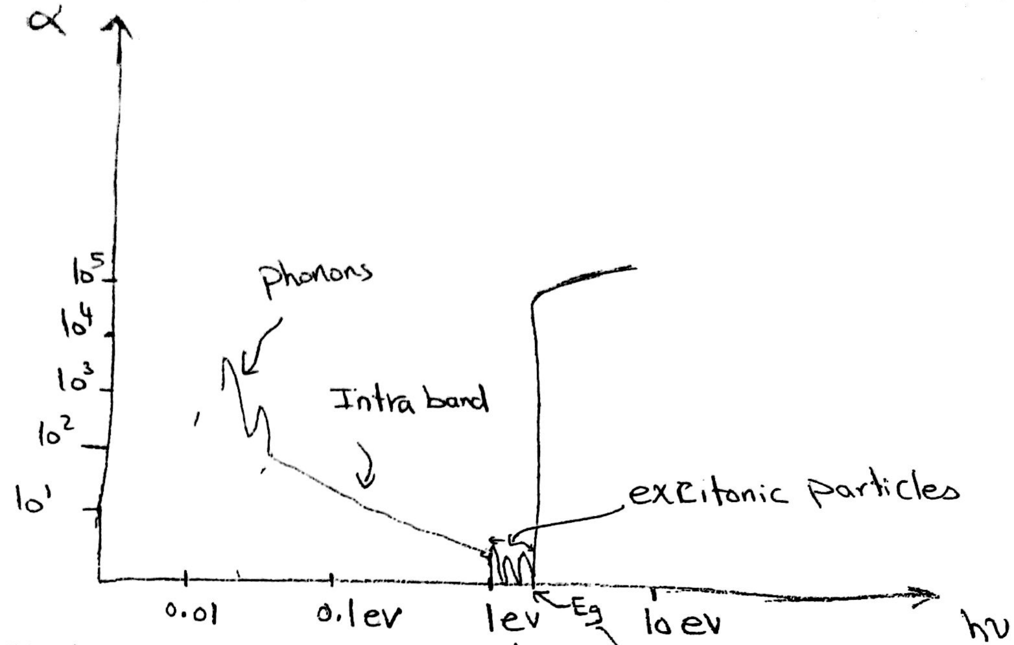
-ve Charge will be in edge of C.B

So, there will be Coloum attraction between them (if they are close in space)
(Binding energy)

Energy between electron-hole ≃ 10meV

at Room temp. → you can't see exciton because KT = 25m

12

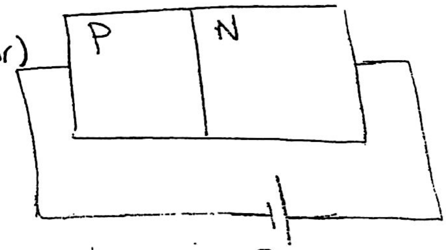


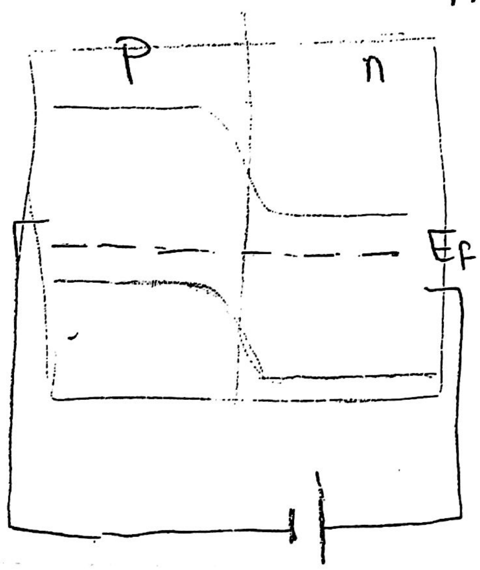
Total Absorption spectrum ↳ 1.42ev (GaAs)

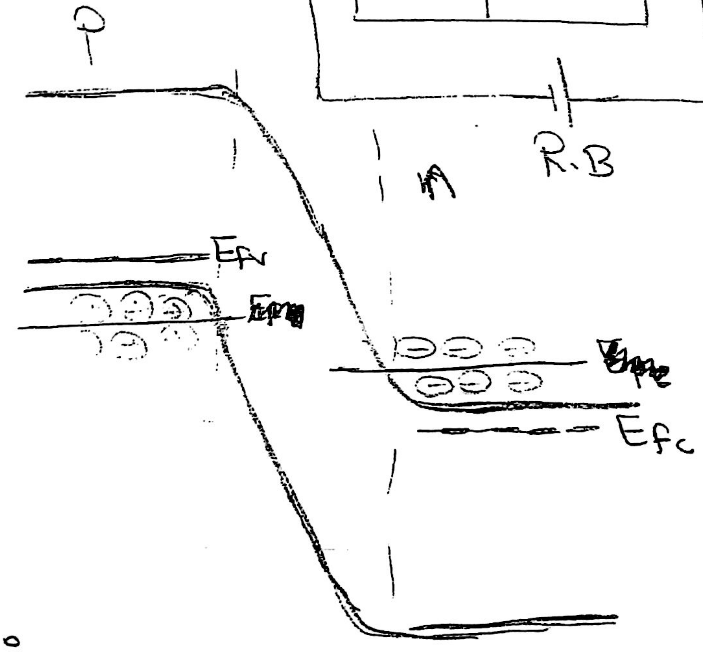
P, N → Silicon

Sheet ④ Function of Device

$\boxed{Q(6)}$ ① (~~attenuator~~) Absorper (photodetector)



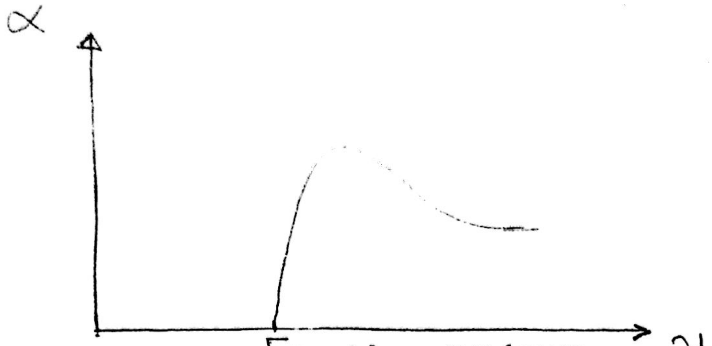




PN-Junction with R.B :

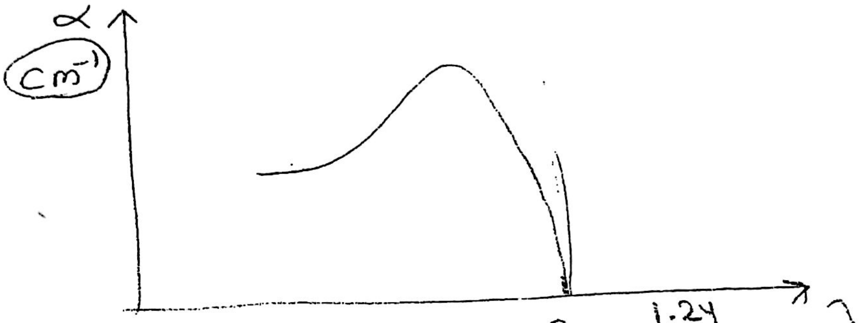
$E_{fv} > E_{fc}$

↳ ∴ $\gamma \rightarrow$ -ve



$\frac{E_g}{h} = \frac{1.1}{h} = 256\ \text{THz}$

Attenuation spectrum



$\lambda_{max} = \frac{1.24}{1.1}$

$= 1.12\ \mu m$

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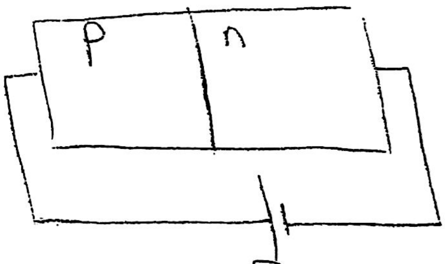
② Device function ⟹ LED (light source

↳ Condition $P_e > P_{abs}$

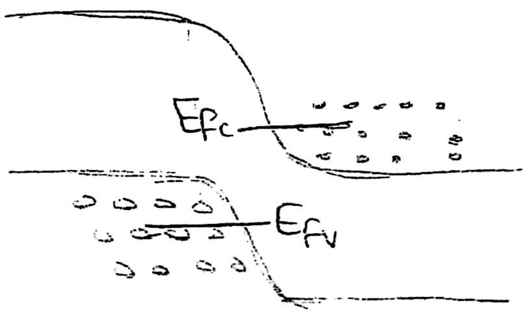
$E_{fc} > E_{fv}$

P, n ⟶ Ga As



F.B

↳ Band Diagram



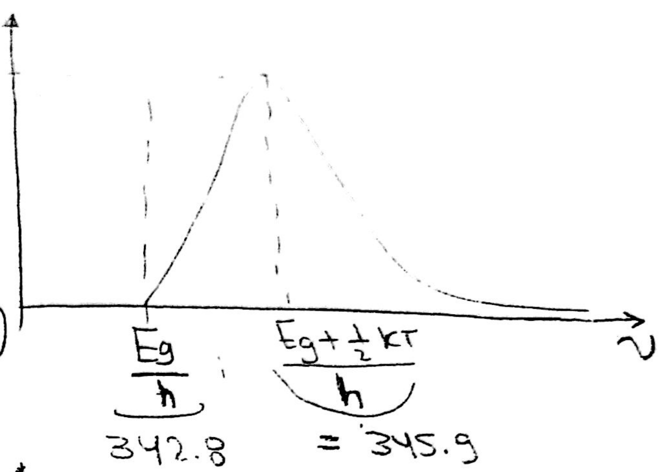
Spontenous emission spectrum:

GaAs

$$\nu_{min} = \frac{E_g}{h} = \frac{1.42}{h}$$

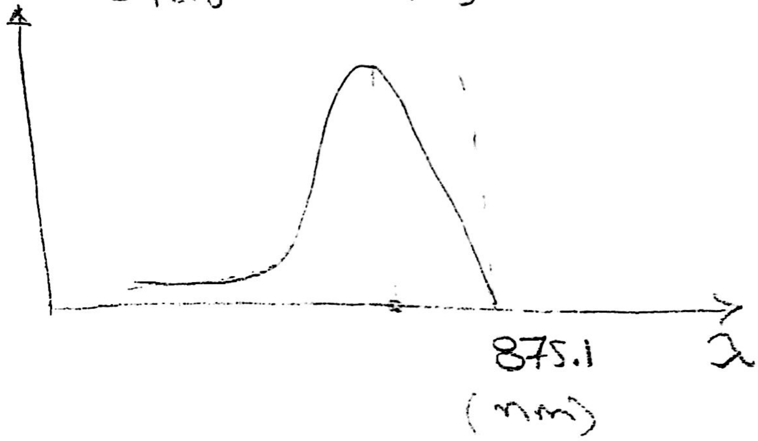
$$= 342.8\ \text{THz}$$

$$\nu\big|_{peak} = 345.9\ \text{THz}$$



$$\lambda_{max} = \frac{c}{\nu_{min}} = 875.1\ \text{nm}$$

$$\lambda\big|_{at\ peak} = 867.3\ \text{nm}$$



(3) → Amplifier

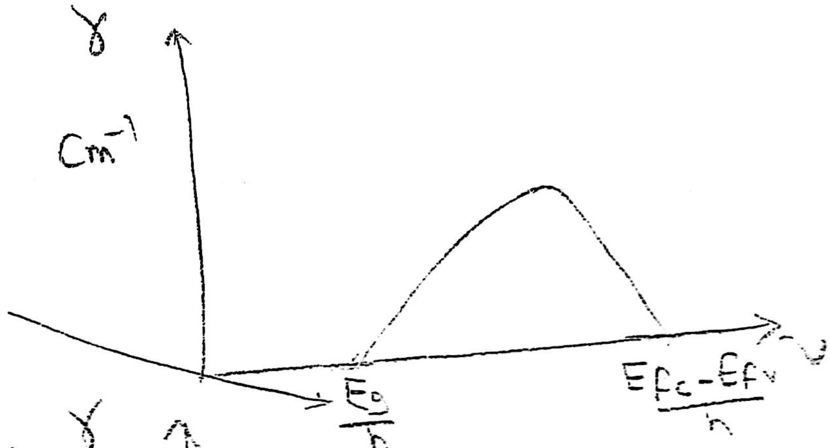
⊛ Band Diagram at page (9)

\+ Draw the spectra (Amp. Gain)

$$E_g\big|_{Al_{0.1}Ga_{0.9}As} = 1.544$$

$$\nu_{min} = 372.8 \times 10^{12}$$

$$\lambda_{max} = \frac{c}{\nu_{min}} = \checkmark$$



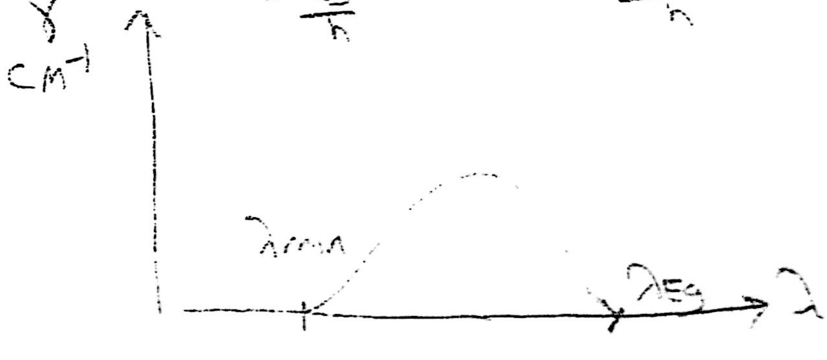


Photo detectors

- Photo emissive
  - Photo-multiplier tube (PMT)
- $\boxed{\text{photo-Conductive}}$: Device that its Conductivity changes with the incident light
  - photo Conductor
  - Photo diodes
    - PIN
    - APD (Avalanch photo diode)
  - photo transistor

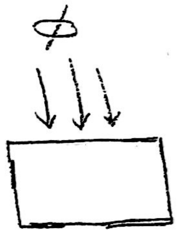
General characteristic of photodetectors:

1. $\eta \rightarrow$ the Quantum efficiency.
2. $R \rightarrow$ Responsivity.
3. $t_r \rightarrow$ Rise time / Impulse response (يحدد ال B.W و يحدد سرعة ال photo detector)
4. $P_{Noise} \rightarrow$ Noise power / dark Current

---

1. The Quantum efficiency:

$$\eta = \frac{\left(\begin{array}{c}\text{Carrier flux Generated}\\ \text{which Contirbute to the}\\ \text{photo current}\end{array}\right)}{\left(\begin{array}{c}\text{Incident Photon}\\ \text{Flux}\end{array}\right)}$$



ϕ = photon Flux

$= \frac{P_{opt}}{h\nu}$

= No. of photons per unit time

$$\therefore \eta = \frac{i_p / e}{P / h\nu} = \frac{i_{ph}}{P_{opt}} \cdot \frac{h\nu}{e}$$

2 Responsivity :

$$R_{\text{photodetector}} = \frac{i}{P_{opt}} \quad A/W$$

tell me → How much current will be generated if i pass P_{opt} (optical power).

$$\eta = \frac{i}{P_{opt}} \cdot \frac{hc}{e\lambda} = R_{det.} \cdot \frac{1.24}{\lambda(\mu m)}$$

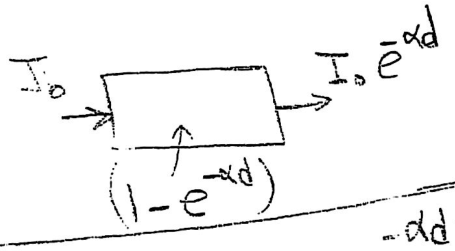
$$\boxed{R_{det.} = \eta \cdot \frac{\lambda(\mu m)}{1.24}}$$

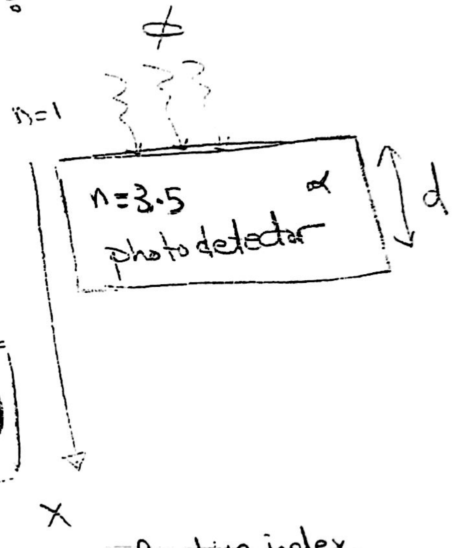
$R \propto \eta$

(if you want to maximize R you want $\eta \to$ max.)

↳ To increase R ⇒ we need to increase η :

① what is η ?





$$\boxed{\text{Fractional no. of Photons Absorped} = \phi(1-R)(1-e^{-\alpha d})}$$

refractive index

دي نتيجه اختلاف الـ n ف جزء من الـ power هينعكس

$(1-R_{ref.})\phi$ ⇐ Detector دي فالقيمه اللي هتدخل لـ

$R_{ref} \to$ refractivity

① ليس كل الـ photons الداخله ف تنتج Current ممكن تنتج phonons مثلاً

② ممكن الـ electron-hole الناتج يحصل بينهم recombine ولا تنتج Current

$0 < \zeta < 1$

$N \rightarrow$ No. of Absorped photons

$\zeta \cdot N \rightarrow$ no. of photons generate Current

$\therefore$ Energy Absorped $= \phi (1-R_{ref.})(1-e^{-\alpha d})\,\zeta$

$$\therefore \eta = \frac{\phi (1-R_{ref.})(1-e^{-\alpha d})\,\zeta}{\phi}$$

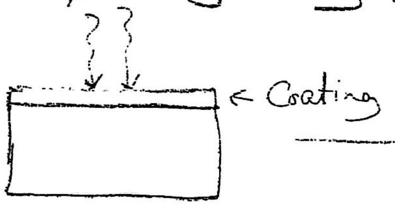
$$\boxed{\eta = (1-R_{ref})(1-e^{-\alpha d})\,\zeta}$$

To $\eta \gg$

① R_{ref} make it $\simeq 0$

How?

By using (Anti Reflection Coating)



$e^{-\alpha d} \simeq 0$

↳ we need to make (αd) to be large

$d \rightarrow$ maximize Thickness of PD

$d \uparrow$

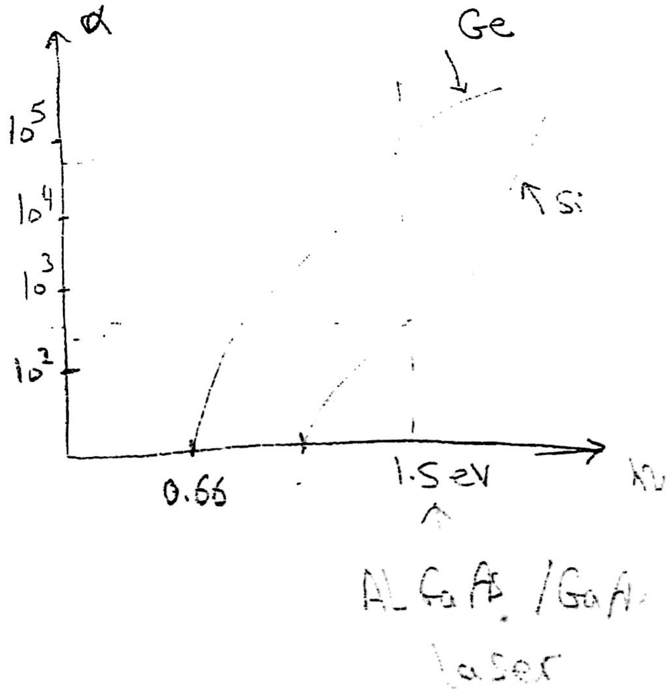
$\zeta \simeq 1$

→ How to maximize α?

$\alpha_{Ge} > \alpha_{Si}$

↳ when i use the Same light Source

→ Then i Can use Ge



3

Note!! Thickness of photo detector depend on α

Ex: IF i need 90% of light to be Absorped

$$\therefore \quad (1 - e^{-\alpha d}) = 0.9$$

$$e^{-\alpha d} = +0.1 \Rightarrow -\alpha d = \ln(0.1)$$

$$\boxed{d = \frac{1}{\alpha} \ln(10)}$$

if i use $\alpha = 20{,}000 \text{ cm}^{-1}$ (Ge)

$$\therefore \quad d = \frac{1}{20{,}000} * 2.303 = 0.115 * 10^{-3} \text{ cm}$$

$$= \underline{1.15 \ \mu m}$$

---

③ $Z \rightarrow$ how to maximize ?

$\uparrow$ no. of Absorped photons that generate Current

By very ~~careful~~ careful fabrication of the detector material.

" To make less defects → less trap States "

لأننا نزيد من سرعة الـ recombination بين الـ electron & hole .

Q3(8) Give reason for:

g) Coating the top of sensor by then transperant layer.

→ To minimize the refractivity (R_{ref})

Then η will increase

as $\eta = (1 - R_{re})(1 - e^{-\alpha d})\zeta$

So → The responsivity will increase

$$\mathcal{R} = \eta \cdot \frac{\lambda (\mu m)}{1.24}$$

[Current generated will increase]

---

[h] Sensor made from Ge is thinner than that made of Si with identical Quantum eff.

→ $\eta = (1 - R_{ref})(1 - e^{-\alpha d})\zeta$

$\alpha_{Si} < \alpha_{Ge} \Rightarrow d_{Si} > d_{Ge}$

(α) vs. ($h\nu$)

+ الرسم ال ← page (3)

Mansoura University	Faculty of Engineering	Electronics and Comm. Dept.	4th Year, Optical Communication Systems	16/12/2015	Updated Sheet #4

Q1) Complete the following sentences with suitable word(s):

a) In dense wavelength division multiplexing,the separation between successive wavelength is equal to ....
b) Double hetero structure is defined as................
c) The Thickness of active material in double heterostructure should be less than..
d) The deBroglie wavelength at T=300K for GaAs with $m^*=0.067m_0$ is equal to...
e) At thermal equilibrium,the probability of emission is.................... than the probability of absorption .
f) The energy of phonons lies within the range ....
g) The momentum of electron is ....that of phonon.
h) The momentum of electron is ....that of photon.
i) The phonon has ....energy and .... momentum.
j) The photon has ....energy and .... momentum.
k) Absorption of energy with .... generates phonons.
l) Absorption of energy (Eg-10mev) generates.. .

Q2) Compare between:

a) Photon and Phonon.
b) Optical Phonon and acoustic Phonon.
c) Radiative transition Non-Radiative transition.
d) Photon assisted transition and phonon assisted transition.
e) Structure Al $_{0.1}$Ga$_{0.9}$ As/GaAs /Al $_{0.1}$ Ga$_{0.9}$ As, thickness of GaAs=15 nm and Al $_{0.1}$Ga$_{0.9}$ As/GaAs /Al $_{0.1}$Ga$_{0.9}$ As, thickness of GaAs=12 nm.
f) The spontaneous emission, stimulated emission, absorption with the aid of(E-K)diagram & applications.
g) Irradiance, Energydensity and Flux
h) Amplifier and attenuation using E-K diagram at T=0 k. → Sec(9) Page(3)
i) Interband transition &Intraband transition.
j) Amplification gain coefficient at T=0K and T= 300k.
k) Quantum efficiency and responsively
l) Carrier transit time and carrier recombination time
m) Sensitivity, dynamic range and linearity of the detector

Q3-Draw the following curves:

a) Rate of spontaneous emission for Ga$_{0.9}$ Al $_{0.1}$ As & Al $_{0.2}$Ga$_{0.9}$ As at T=300k
b) Rate of spontaneous emission for Ga$_{0.9}$ Al $_{0.1}$ As at T=300k & T=200k & T=400k
c) Typical attenuation curves for Si, Ge, GaAs, GaN
d) Responsively vs. wavelength for si and In Ga As

Q4) Given Al $_{0.2}$Ga$_{0.8}$ As/GaAs/Al $_{0.2}$Ga$_{0.8}$ As

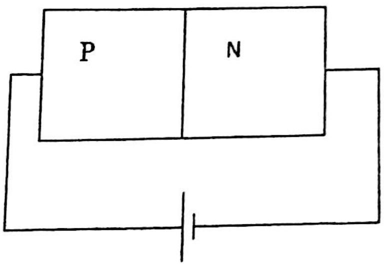
a) Draw the structure, defining (determine) the available thickness for GaAs layer
b) Draw the band diagram for the structure qualitatively.
c) Explain the operation of the structure with the aid of (b) and determine the application that this device can be used for.
d) Determine the maximum and minimum emitted wavelengths.

Q5)Estimate the following relation

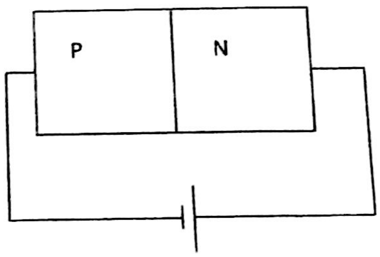
a) Optical Joint of state $\rho_{c,v}(\upsilon)$.
b) Rate of spontaneous emission.
c) The probability of emission and absorption at thermal equilibrium.
d) The probabilities of emission and absorption at quasi thermal equilibrium.
e) K-selection rule.
f) Amplification gain in stimulated emission
g) Conditions for amplification (stimulated emission)

Q6) Given

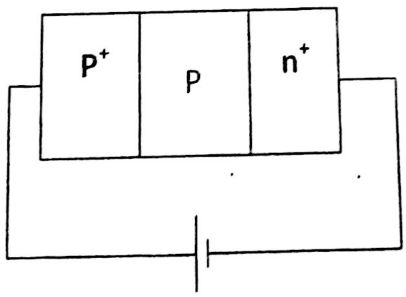
P layer and N layer are made of Ga As



P layer and N layer are made of Si



P $^{+}$: Al $_{0.1}$Ga$_{0.9}$ As , P: Ga As , n $^{+}$: Al $_{0.1}$Ga$_{0.9}$ As



a)Draw the band diagram for each structure

b) Explain the operation and define the function of each device.

c) Draw the variations of the spectra (spontaneous emission, attenuation constant and amplification gain) of each device vs.

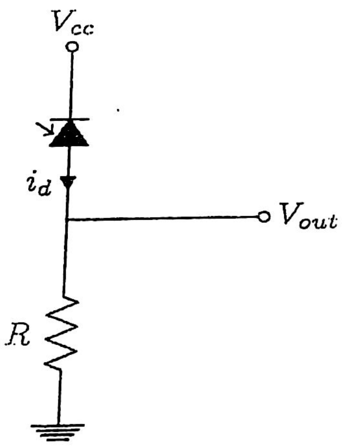
- υ (Frequency)
- λ (wavelength)

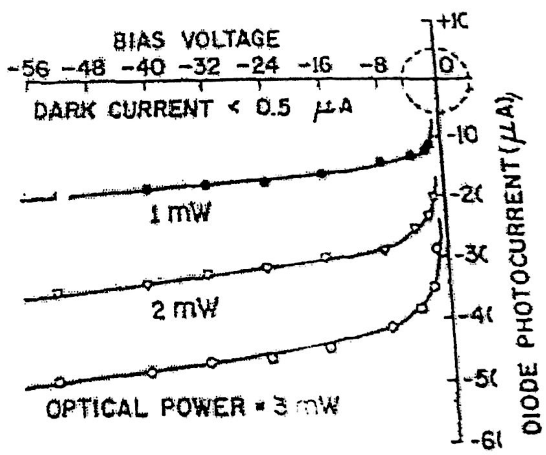
Q7 Given semiconductor amplifier $In_{1-x}Ga_x\ As_{1-y}P_y$ with E_g=1.12 ev& peak gain coefficient=60 cm^{-1} and B.W =300 nm, draw the variation of gain coefficientvs. υ (Frequency) and λ (wavelength)

Q8. Give reason for

a) Si absorbs photon with energy <1.1.ev
b) The width of P-layer in PN junction detector is less than N-layer
c) InGaAs is preferred for designing fast response detector
d) Ge is not preferred for designing sensitive detector
e) Si is preferred for designing solar cells
f) Quantum well structures are suitable for DWDM
lec (40 g) Coating the top of sensor by thin transparent conductive layer
h) Sensor made from Ge is thinner than that made of Si with identical quantum efficiencies
i) Purified materials are necessary for designing sensor with goodresponsively
j) Si is used sensor within the wavelength range 300 nm up to 1100n m only

Q9. Given the circuit below, with V_{cc} = 24 volt, R= 12 MΩ





a) Draw the load line of the circuit, the output voltage vs. the incident power
b) ~~Calculate the dynamic range and how to increase the dynamic range~~
c) Calculate the sensitivity and how to increase the sensitivity
d) Calculate the output noise power and how to decrease it.

Q10. Explain the function, advantage of the PIN diode and give practical design.

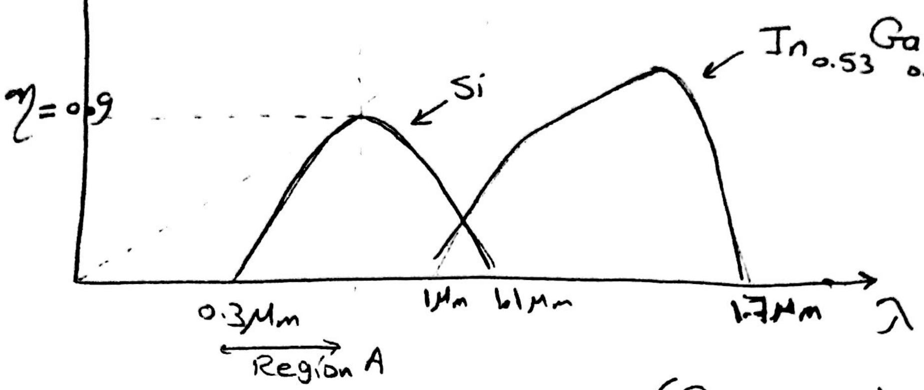
Price
Code : [illegible]

رابعة اتصالات

مقرر optics

part(١٥)

→ j ... is used as sensor within wave length range (300 nm → 1100nm)



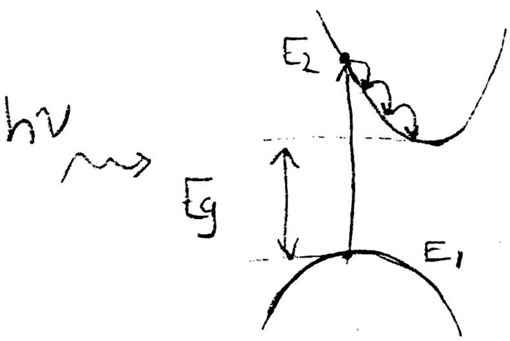
↳ Silicon has $E_g = 1.1\,eV$ ($\lambda_g = 1\,\mu m$)

↳ photons have energy > 1.1 eV

Si must absorp them and generate Current ($\eta \gg$ for $\lambda < 1.1\,\mu m$)

↳ η goes down in A Region:

1] Generation of hot Carriers

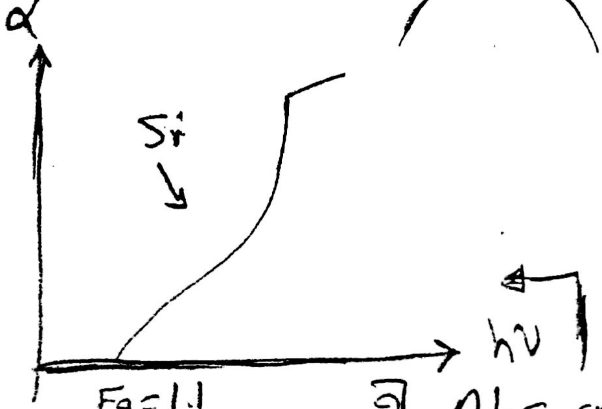


When $h\nu > E_g$

electron Jumps from $E_1 \to E_2$

This electron Called hot electron because it loss energy Through Thermalization (Generate phonons)

→ So recombination take place Very Quickly



2] Absorption near the surface (recombination Because of trap State)

for $h\nu > E_g \Rightarrow$ $\alpha \to$ will be large

Then $d \to$ will be small

↳ because ($e^{-\alpha d}$)

6

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Note

① At 1.55 μm (fiber Application)

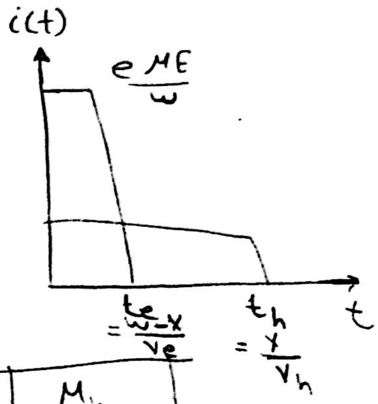
↳ InGaAs is Commonly used

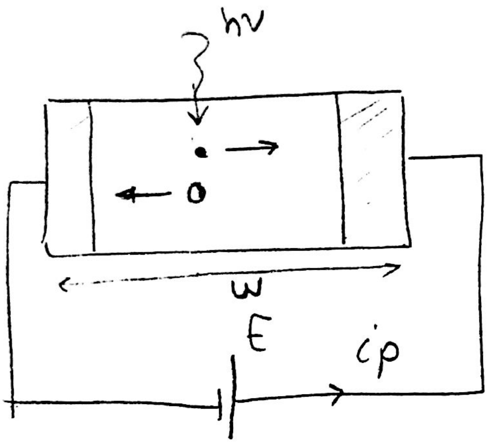
② For Solar cell at (0.3 μm → 0.8 μm)

↳ Silicon is Commonly used detector

---

[3] Response time (How fast the detector is?)





$$i(t) = -\frac{q\,v(t)}{w}$$

$$v(t) = \mu E$$

Material	μ_e	μ_h
Si	1500	450
InGaAs	14,000	400

↳ To increase the speed of detector?

[1] Choose material with high mobility.
(Ex: InGaAs)

[2] Reduce the dimensions of detector
(Active layer)

[3] Apply Electric field E to help Carriers to move fast.

[illegible]

③ In GaAs is preferred for designing fast response detector

Ⓓ Because it has ~~low~~ large values of μ_e, μ_h and $V_{sat} = 10^7$

(very sharp impulse response)

يعني بمجرد ما اسقط فوتونات هحصل على تيار في زمن قليل

Note ※ Impulse Response depend on 2-factors

<u>transit time</u>

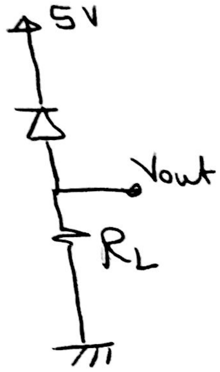
$$t_e = \frac{w}{\mu E}$$

→ To minimize it

* increase μ and E
* decrease w

(ده اللي اتكلمنا عنه في الصفحة اللي فاتت)

Time Constant of the Circuit



$$\tau = R_L \cdot C$$

↑ Junction Cap.

$$f = \frac{1}{2\pi R_L C}$$

<u>At Detector</u> Data Sheet

$\tau = 0.3\,ns \rightarrow$ at $R_L = 50\,\Omega$

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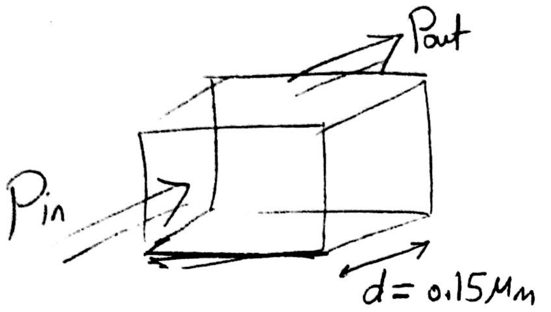
EX8 Given PIN Photodiode made of $In_{0.53}Ga_{0.67}As$

a if the Thickness of I-layer $= 0.15\,\mu m$ and Absorption Coeff. $\alpha = 1.5\,\mu m^{-1}$ at $\lambda = 1300\,nm$

→ Determine the percentage of Absorped photons by PIN diode.



$$P_{out} = P_{in}\, e^{-\alpha d}$$

$$= P_{in}\left(e^{-(0.15 * 1.5)}\right)$$

$$\cong 0.8\, P_{in}$$

$$\therefore P_{absorped} = \frac{P_{in} - 0.8\,P_{in}}{P_{in}} * 100$$

$$P_{abs} = 20\%$$

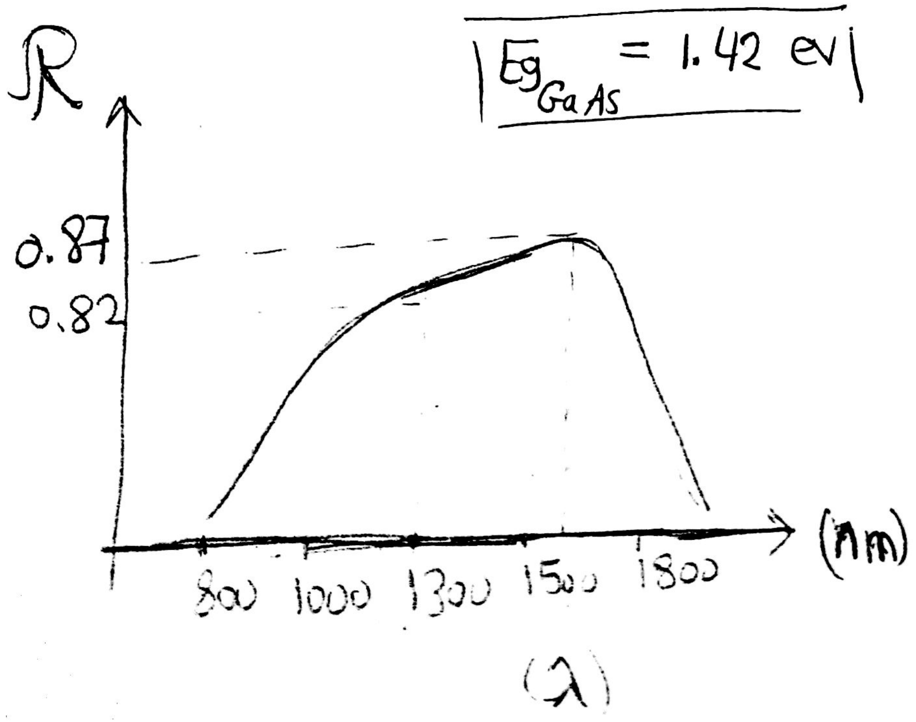
b Given Responsivity Curve for $In_{0.53}Ga_{0.67}As$

i) Determine the Band Gap?

ii) Determine the incident optical Power to generate $I_{ph} = 10\,nA$ at $\lambda = 1.55\,\mu m$

iii) Will the PIN Detector detect the maximum emitted λ from Laser diode made of GaAs?

$$\boxed{E_{g_{GaAs}} = 1.42\ eV}$$



~Sol~ i) $\lambda_g = 1800\ nm \rightarrow \underline{E_g} = \frac{1.24}{\lambda_g(\mu m)} = \frac{1.24}{1.8} = 0.69\ ev$

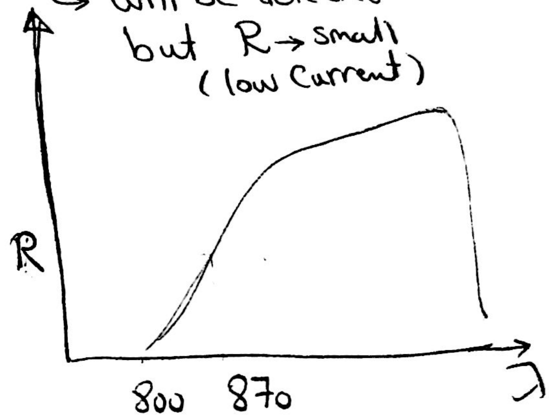
ii) $R\Big|_{\lambda=1.55} = \frac{i_{ph}}{P_{opt}} \Rightarrow$ From Curve at $\lambda = 1.55\ \mu m \Rightarrow R = 0.87$

$$P_{opt} = \frac{i_{ph}}{R} = \frac{10\,nA}{0.87} = 11.5\ nW$$

iii) GaAS $\rightarrow E_g = 1.42\ eV$

$$\lambda_g = \frac{1.24}{1.42} = \underline{870\,nm}$$

↳ will be detected but R → small (low current)



Note// $\underline{\text{Dark Current:}}$

The reverse current when there is no incident photons

$\underline{\text{Typical Values:}}$

Si ~ 1nA

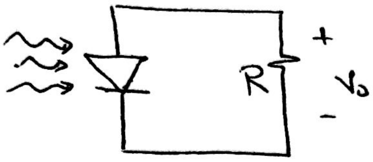
Ge ~ 200nA

InGaAs ~ 100nA

Photo diodes

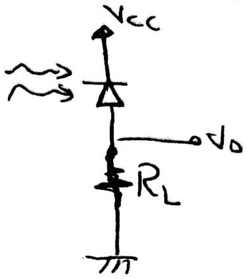
I] Two modes of operations

→ I] Photo Voltaic



* No Reverse Bias Applied
* Slower Device

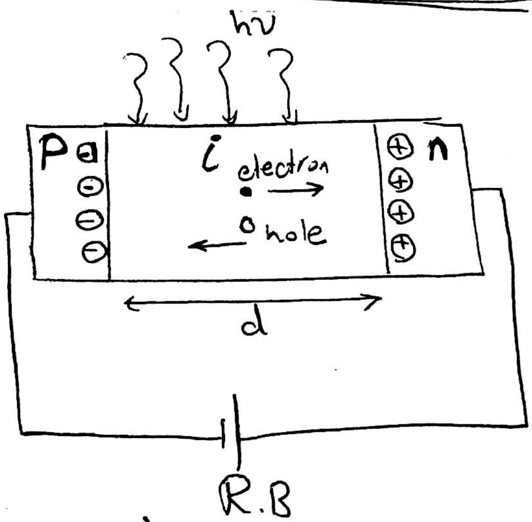
II] Photo Conductive



* Apply Reverse Bias
* More Conductive
* high Responsivity
* Speed device

* PIN Diode

(positive intrinsic Negative)



- Introduction the intrinsic Region :

* Increase area of Capturing light (large η)

* $C = \frac{\varepsilon A}{d}$, $d \rightarrow$ is large $\Rightarrow$ ∴ C is Small $\Rightarrow$ Fast Responce $f = \frac{1}{2\pi R_L C}$

أ/ معاذ

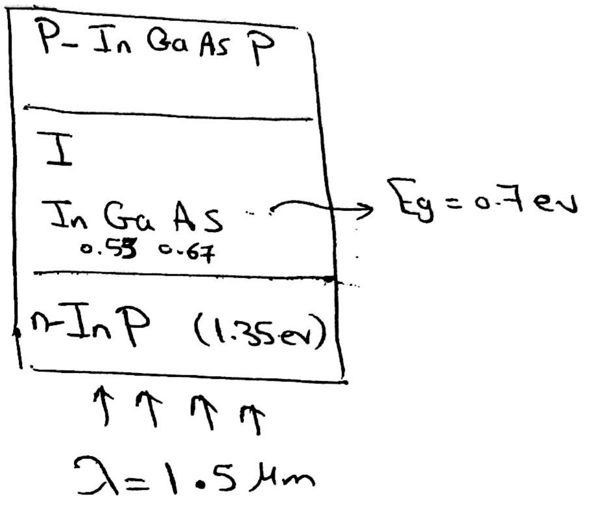
↳ Practical PIN Design :

InP → $E_g = 1.35\,ev$

and incident $\lambda = 1.5\,\mu m$ $(0.7\,ev)$

So, this layer works as transparent material

$E_g > E_g|_{incident}$



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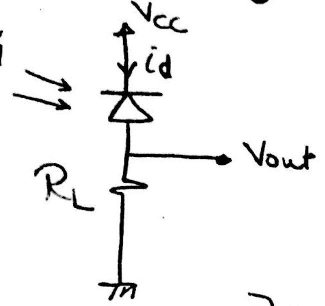
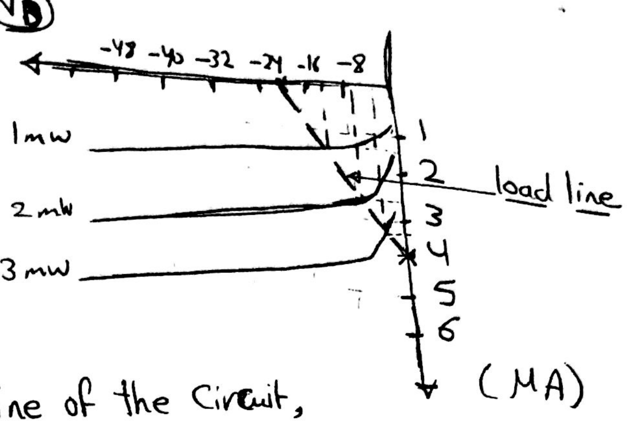
Given the Circuit below, with $V_{cc} = 20$ Volt, $R = 5\ M\Omega$





a) Draw the load line of the Circuit, the o/p Voltage Vs. the incident power

b) Calculate the dynamic Range and how to increase the dynamic range.

c) Calculate the Sensitivity and how to increase it.

d) Calculate the o/p noise power and how to decrease it.

Sol: load line:

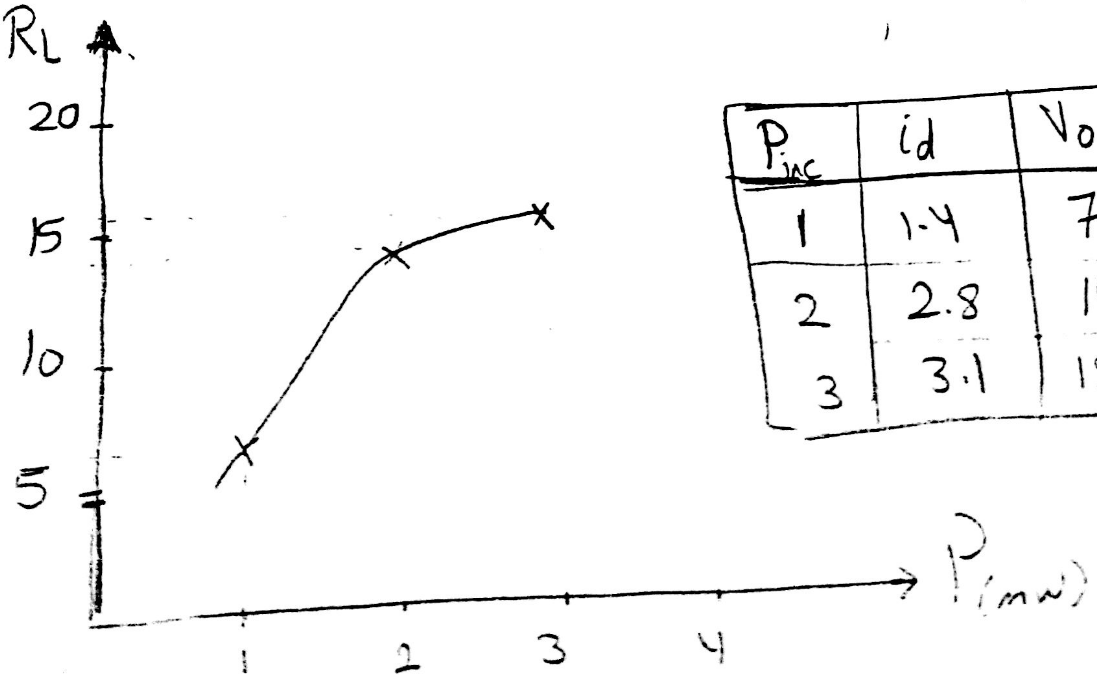
$$V_{cc} + V_d + i_d R_L = 0$$

$$i_d = -\frac{V_{cc}}{R_L} - \frac{V_d}{R_L}$$

at $i_d = 0 \rightarrow V_d = -20$

at $V_d = 0 \rightarrow i_d = 4\ MA$

$V_o = i_d R_L$



P_{inc}	i_d	$V_o = i_d * R_L$
1	1.4	7
2	2.8	14
3	3.1	15.5

b) **Dynamic Range** $= \left.\dfrac{\text{max Power}}{\text{min power}}\right|_{dB}$

$$= 10 \log \frac{15.5 * 10^{-3}}{7 * 10^{-3}} = 3.4 \text{ dB}$$

↳ To increase Dynamic Range → Decrease load Resistance

c) **Sensitivity** : (min. power generate Current)

$S = 1mW$

↳ To increase Sensitivity → use large R_L

d) **Noise power**

given ↳ Dark Current $\leq 0.5\mu A$

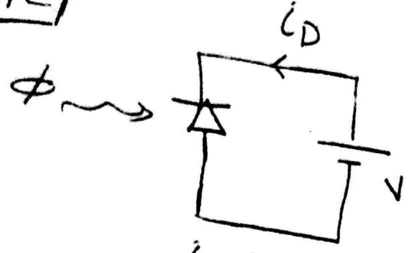
$$P_{noise} = (i_d)^2 R_L = (0.5 * 10^{-6})^2 \cdot 5 * 10^{6} = 1.25 \mu\text{watt}$$

↳ To decrease Noise power:

↳ decrease load Resistance

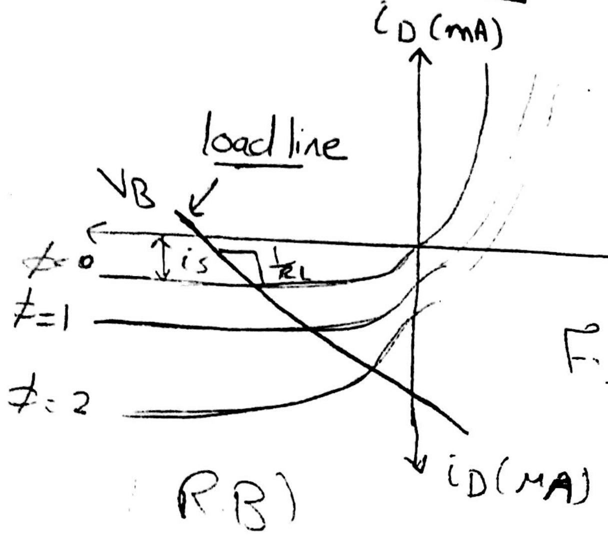
٥

Note



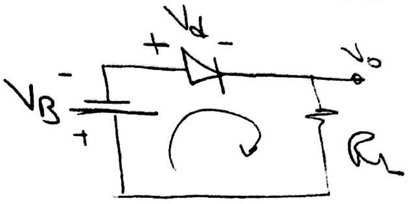
→ $i_D = i_s\,(e^{\frac{eV}{KT}} - 1) - i_p$

↑ Photo Generated Current



F.B

→



$V_B + V_d + i_d R_L = 0$

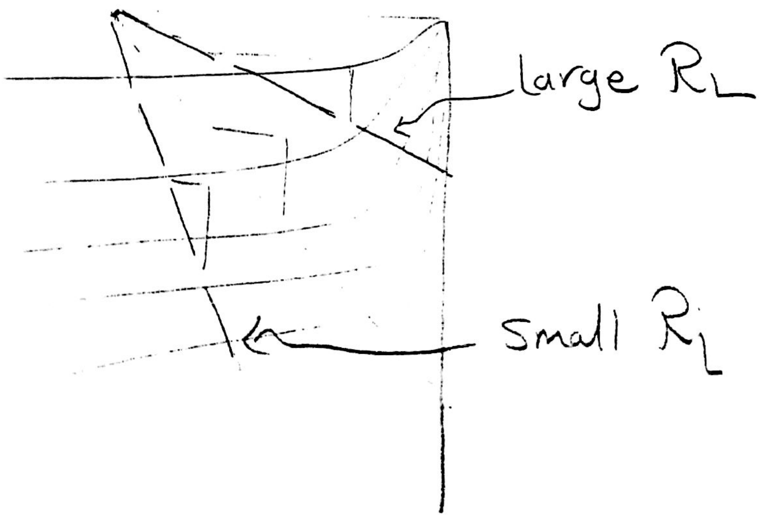
load line

↳ $i_d = -\frac{1}{R_L} V_d - \frac{V_B}{R_L}$

Const.

جهد المصدر $V_B = \text{Const.}$

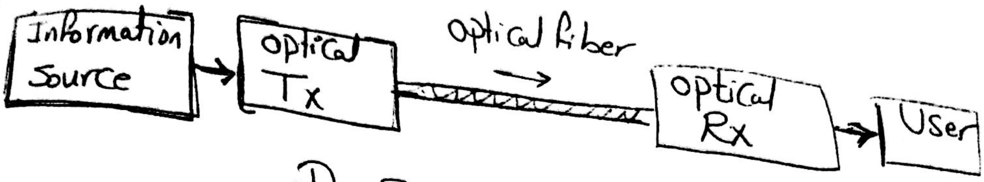
مقاومة الحمل $R_L = \text{Const}$



↳ Small R_L → عدد النقاط اللي هيتقاطع فيها الـ load line مع الـ Curve هتزيد

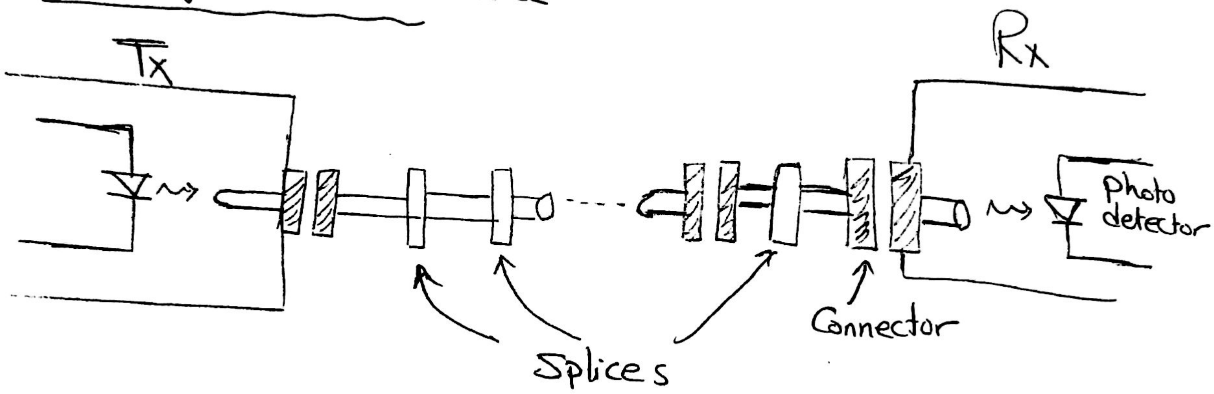
↳ يعني الـ Dynamic Range هيزيد

Fiber link Design:



① Simple point-to-point link

② Optical power loss-model



Connectors → ① Connect fiber to Rx and Tx Blocks
② Testing and measuring purposes.

Splices: ↳ permenent Connection

↳ To design fiber link:
- [1] The length of link (Km)
- ② Bit rate (Mb/s)
- ③ Bit error rate

① select Source:

LED → 100 μ watt

Laser diode → 1mW → 0 dBm

$$= 10 \log \frac{10^{-3}}{10^{-3}} = 0$$

link → Power Budget Calculations:

P_s = Power from transmitter in dBm

P_r = Sensitivity of Rx in dBm from given BER

Max. allowable loss $\left[\alpha_{max} = P_s - P_r\right]$

$$\alpha_{max} = \alpha_{fiber} + \alpha_{Connectors} + \alpha_{splice} + \alpha_{sys.}$$

$$\alpha_{fiber} = \alpha_{max} - \left[\alpha_{Conn.} + \alpha_{splice} + \alpha_{sys.}\right]$$

Safety Margin 6dB

Power limited link length $= \dfrac{\alpha_{fiber}}{\text{loss}/\text{Km}}$

→ Beyond this distance the SNR is below the Acceptable limit.

Rise time Budget

Rise time analysis gives effective B.W of link:

$$t_{sys} = \sqrt{t_{Tx}^2 + D^2 \sigma_\lambda^2 L^2 + t_{Rx}^2}$$

for satisfactory operation of the link

$$t_{sys} \leq 0.7\, T_b$$

σ_λ → spectral width of optical source

D → material dispersion

T_b → pulse duration

Link Power Budget:

is an accounting procedure in which one Calculates How much power can be lost between Tx and Rx for given reciver sensitivity (which depends on bit rate)

Rise time Budget:

is an accounting produce in Which one Calculates how much pulse spreading can be tolerated between Tx and Rx for a given Tx. rise time, ~~[illegible]~~ receiver rise time and dispersion due to fibre.

Ex:

$\sigma_\lambda = 0.1\,nm$, $P_{Tx} = -8\,dB$

$P_{Rx} = -34\,dB$

$D = 5\,ps/Km/nm$

5 Splice → each has loss = 0.1 dB/Km
2 Connector → " " " = 0.75 dB/Km
$\alpha = 0.2$ dB/km at $\lambda = 1550$ nm

↳ Calculate link length ?
↳ Calculate Rise time ?

~SoL~

$$\alpha_{max} = P_t - P_r = -8-(-34) = 26\,dB$$

$$\alpha_{Connector} = 2 * 0.75$$

$$\alpha_{splice} = 5 * 0.1$$

Safty Margin

$$\therefore L = \frac{26 - [(2*0.75) + (5*0.1) + 6\,dB]}{0.2}$$

$$\boxed{L = 90\,Km}$$

↳ you ~~will~~ won't need Amp. ~~Repeater~~ for L < 90 Km
SNR → acceptable

انك تحتاج amp. بعد ال 90km وتحتاج repeater بعد ال $2*10^3$ Km

$$t_{Disp.} = D \cdot \sigma_\lambda \cdot L_{RTmax}$$

$T_b = 10^{-9}$, $D = 5\,ps/Km/nm$, $\sigma_\lambda = 0.1\,nm$

$$L_{RTmax} = \frac{10^{-9}}{0.1 * 5 * 10^{-12}} = \underline{2*10^3\,Km}$$

Signal Can travel without distortion to $2*10^3$ Km , but SNR become unacceptable after 90 Km